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USE OF THE MAGNUS FORCE IN THE MODIFIED POINT MASS TRAJECTORY MODEL

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A method is presented for determining the Magnus force coefficient for use with the Modified Point Mass Trajectory model, to improve the simulated time of flight, based on the firing table experimental range firing impact and time-of-flight data. A comparison is made with the Magnus force coefficients determined from aerodynamic testing for the 155mm, HE, M107 and 8-Inch, HE, RA, M650 projectiles. The Magnus force coefficients contained in the firing table data base for artillery projectiles are presented. Keywords:

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I. Introduction

The Modified Point Mass Trajectory Model [1,2] is the primary method of trajectory simulation used in the preparation of Firing Tables. This model requires three types of input data: projectile mass properties, aerodynamic coefficients and the performance parameters determined from experimental range testing. This report discusses the significance of the Magnus force coefficient and a method of determining the Magnus force coefficient for trajectory simulation using the Modified Point Mass Trajectory model. It also compares the Magnus force coefficients of the 155mm, HE, M107 and the 8-Inch, HE, RA, M650 projectiles with results based on aerodynamic testing reported by MacAllister and Krial [3] and by Piddington,[4] respectively.

II. Discussion and Results

The 155mm, HE, M107 projectile fired with propelling charge M119A1, charge 8 (684 metres per second muzzle velocity) is used as an example to show the effect of the Magnus force on trajectory time of flight. Figure 1 shows the trajectory height versus range for projectiles fired with quadrant elevations of 400, 800 and 1200 mils. Figure 2 presents the Modified Point Mass Trajectory model estimate for the yaw of repose versus time of flight for the three trajectories. The yaw of repose is the steady-state angle of attack due to gravity-induced curvature of the trajectory.[5] The nose of a spinning projectile is to the right of its flight path; therefore, the Magnus force, which is perpendicular to the yaw of repose, results in an acceleration in the vertical plane with the acceleration increasing proportionally with the yaw of repose.

Artillery projectiles fired at quadrant elevations up to approximately 1300 mils will normally function properly; however, projectiles fired at higher quadrant elevations exhibit erratic flight performance, such as drift to the left, base first impacts, large range and deflection dispersion, etc.[6] A yaw of repose limit of .6 radian (34.4 degrees), based on experimental range firings, has been included in the Modified Point Mass Trajectory model to determine the maximum firing quadrant elevation used in the preparation of aiming data.[7]

The form factor, a multiplier on the total drag term, is the parameter used in the Modified Point Mass Trajectory model to achieve a match with the experimental range firing impact data. Therefore, to obtain the same range with and without the Magnus force coefficient, the form factor was varied. Table 1 presents trajectory simulations to the same range, with and without a Magnus force coefficient ($-.75$), for the 155mm, HE, M107 projectile. The same range was obtained by increasing the form factor by 1.0, 1.2 and 1.3 percent for the quadrant elevations 400, 800 and 1200 mils, respectively. The value of the Magnus force coefficient was determined from experimental range firing impact and time-of-flight data for the projectile fired with propelling charges: M3A1, charges 1G, 2G, 3G, 4G and 5G; M4A2, charges 3W, 4W, 5W, 6W and 7W; and M119A1 charge 8 at quadrant elevations from 200 mils to 1250 mils. The inclusion of the Magnus force

coefficient increases the time of flight .15, .35 and 1.11 seconds for the charge 8 simulations at quadrant elevations of 400, 800 and 1200 mils, respectively.

The precision probable error in functioning time for modern mechanical and electronic time fuzes is less than .30 and .05 seconds, respectively. Therefore, the Magnus force coefficient is included in the Modified Point Mass Trajectory simulation model.

Table 1. Significance of Magnus Force Coefficient ($C_{N_{p\alpha}}$) for Projectile 155mm, HE, M107 Fired with Propelling Charge M119A1.

Quadrant Elevation (Mils)	Time of Flight (Seconds)		
	$C_{N_{p\alpha}} = 0$	$C_{N_{p\alpha}} = -.75$	Δ
400	39.31	39.46	.15
800	67.91	68.26	.35
1200	89.75	90.86	1.11

The Magnus force coefficient is difficult to determine by aerodynamic testing and is not normally available. Therefore, an alternative method based on experimental range firing impact and time-of-flight data has been developed to determine the Magnus force coefficient for use with the Modified Point Mass Trajectory model. The Magnus force coefficient is determined by varying the coefficient until the overall difference between the simulated and mean observed times of flight is acceptable for the applicable propellant charges (muzzle velocities) and quadrant elevations. The Magnus force coefficient (−.75) was determined for the 155mm, HE, M107 projectile using this iterative process. Figures 3 through 8 show the difference between the mean observed and simulated time of flight (mean observed minus simulated) versus simulated time of flight when a constant Magnus force coefficient is used in the trajectory model. The figures present results for projectiles fired with propellant charges: M3A1, charges 1G, 3G and 5G; M4A2, charges 5W and 7W; and M119A1, charge 8. The approximate muzzle velocities for these charges are: 208, 276, 376, 397, 568 and 684 metres per second, respectively. Each point represents the difference between the mean observed and simulated time of flight for a group of five to ten projectiles and each symbol represents a different firing program. The variation in the results is probably due to the difficulty in measuring the time of flight with stop watches, since it is difficult to determine the zero time and impact time needed to manually start and stop the watches. Figures 3 through 8 demonstrate that the method can be used to obtain an acceptable mean difference between the observed and simulated time-of-flight results for the M107 projectile. "Acceptable" here implies that this mean difference has no overall bias and that individual charge bias can be compensated for by a simple correction to the

computed time-of-flight. This method seems to have the capability of extracting a good approximate value for the Magnus force coefficient from the data, even though there are large occasion-to-occasion differences between the observed and simulated time-of-flight results.

Figures 9 and 10 show a comparison of the Magnus force coefficient determined from experimental range impact and time-of-flight firings with values of the Magnus force coefficient determined from aerodynamic test data. Figure 9 is Figure 26 of reference 3 and Figure 10 is Figure 9 of reference 4, showing the Magnus force coefficients based on aerodynamic testing for the 155mm, HE, M107 and 8-Inch, HE, RA, M650 projectiles, respectively. Also shown on the figures is the Magnus force coefficient for the projectiles, based on the experimental range impact and time-of-flight firings. The comparison shows that the value of the coefficient determined from the range firing data is in good agreement with the subsonic results obtained from aerodynamic range testing for the 155mm, M107 projectile as reported by MacAllister and Krial (Reference 3) and the 8-Inch, M650 projectile as reported by Piddington (Reference 4). The Magnus force coefficient determined from the experimental range impact and time-of-flight firings would be expected to represent the subsonic value. This is because the effect of the Magnus force on the trajectory is proportional to the yaw of repose and normally subsonic velocities and large yaws of repose occur simultaneously for artillery projectiles.

Table 2 presents a summary of the Magnus force coefficients contained in the Firing Table data base for artillery projectiles. These values are based on ballistic analysis of the experimental range firing impact and time-of-flight data.

Table 2. Firing Table Data Base Magnus Force Coefficients ($C_{N_{p\alpha}}$).

Projectile Diameter	Projectile Shape					
	M1		Long Range		Cargo	
	Projectile	$C_{N_{p\alpha}}$	Projectile	$C_{N_{p\alpha}}$	Projectile	$C_{N_{p\alpha}}$
105mm	M1	−.76	M548	−.40	-	-
155mm	M107	−.75	M549A1	−.50	M483A1	−.50
175mm	-	-	M437A2	−.66	-	-
8-Inch	M106	−.38	M650	−1.00	M509A1	−.50

III. Conclusions

The inclusion of the Magnus force coefficient significantly improves the trajectory time-of-flight results of the Modified Point Mass Trajectory model. The Magnus force coefficients for the 155mm, HE, M107 and 8-Inch, HE, RA, M650 projectiles based on the experimental range firing impact and time-of-flight data are in good agreement with the results based on the aerodynamic testing. The Magnus force coefficients determined from the experimental range firing impact and time-of-flight data are of similar magnitude for the different shapes (M1, long range, and cargo) and sizes (105mm, 155mm, 175mm, and 8-Inch) of artillery projectiles.

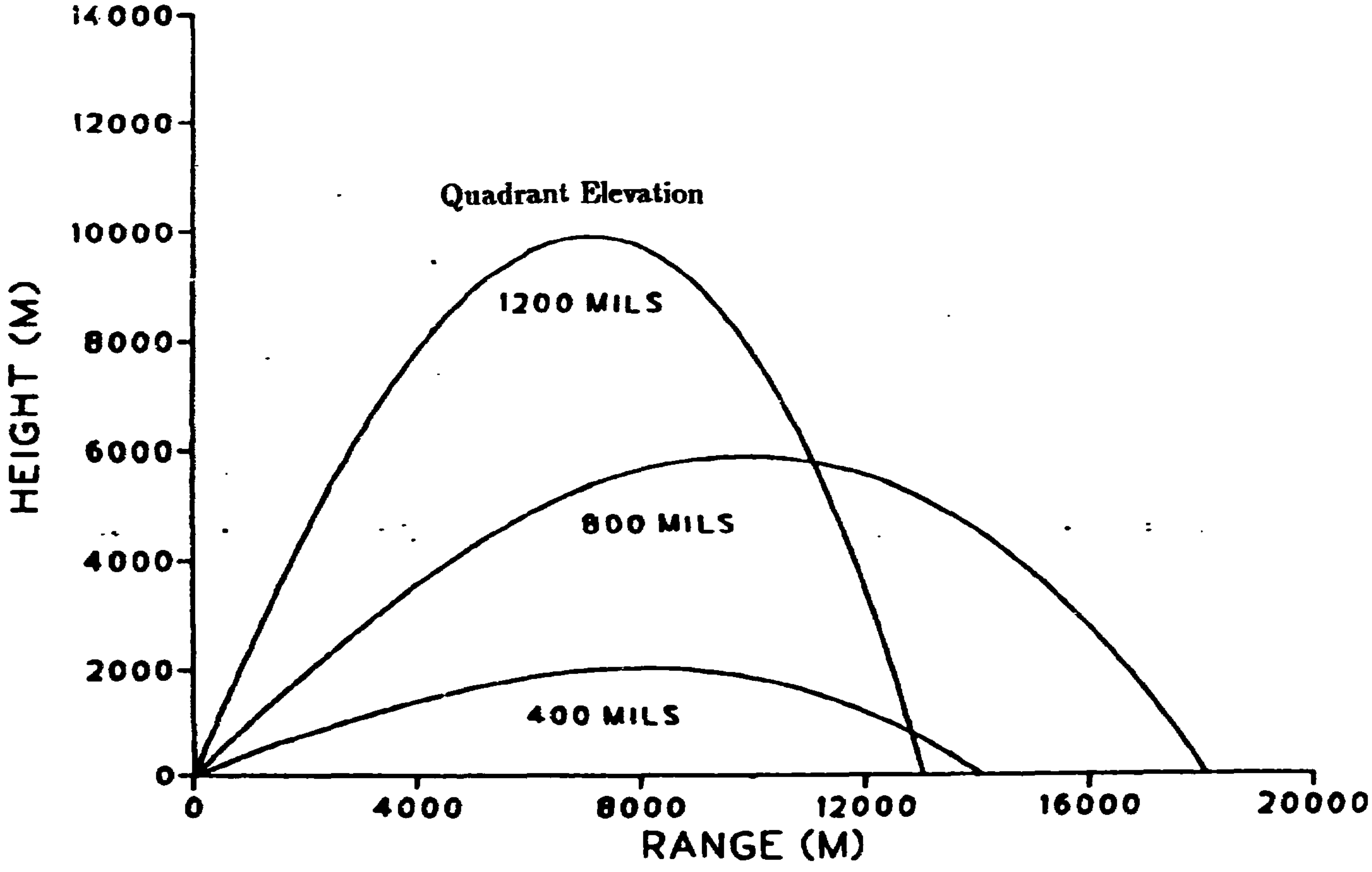

Figure 1. Trajectory height versus range for projectile 155mm HE, M107, fired with propelling charge M119A1, charge 8.

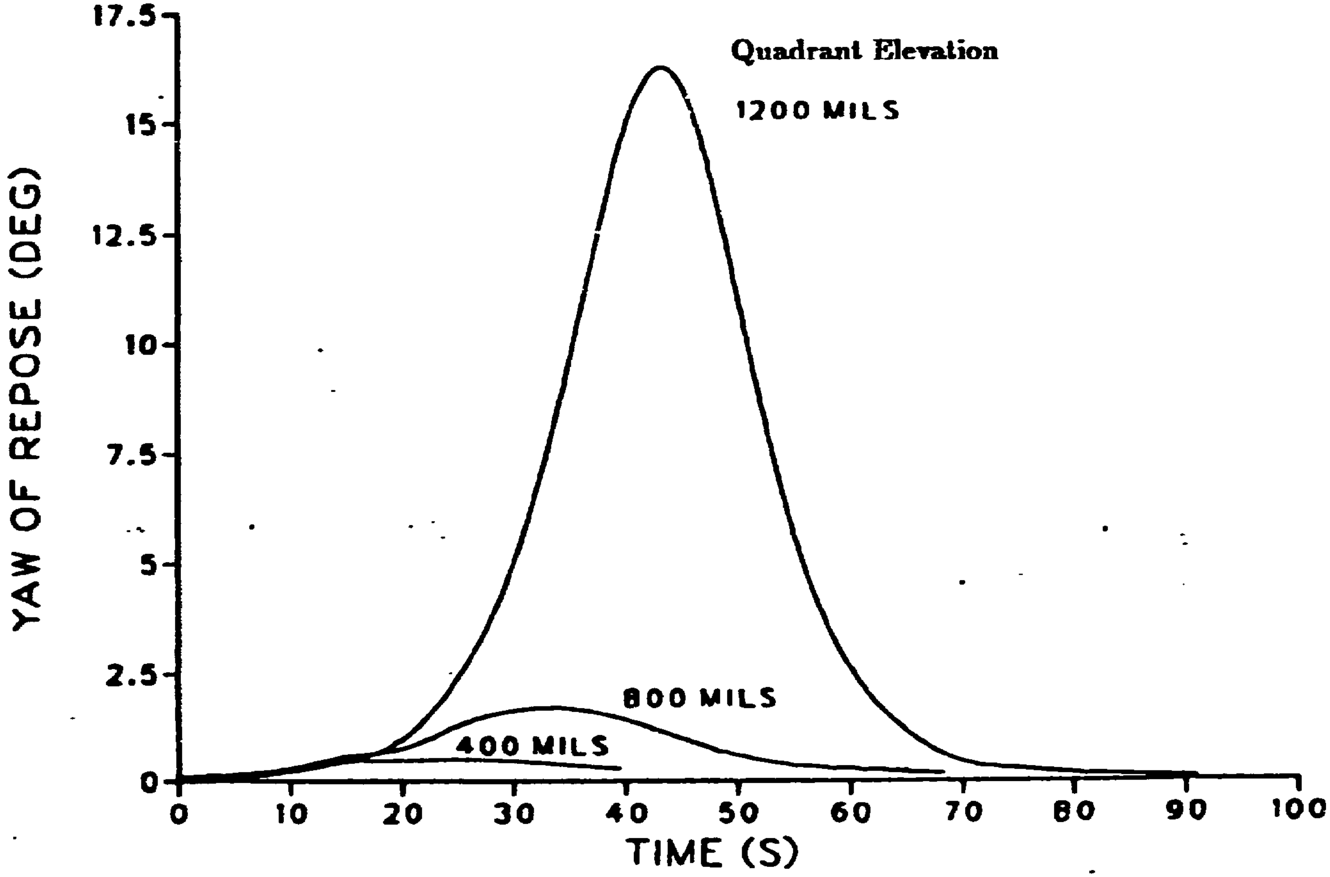

Figure 2. Estimated yaw of repose versus time of flight for projectile 155mm, HE, M107, fired with propelling charge M119A1, charge 8.

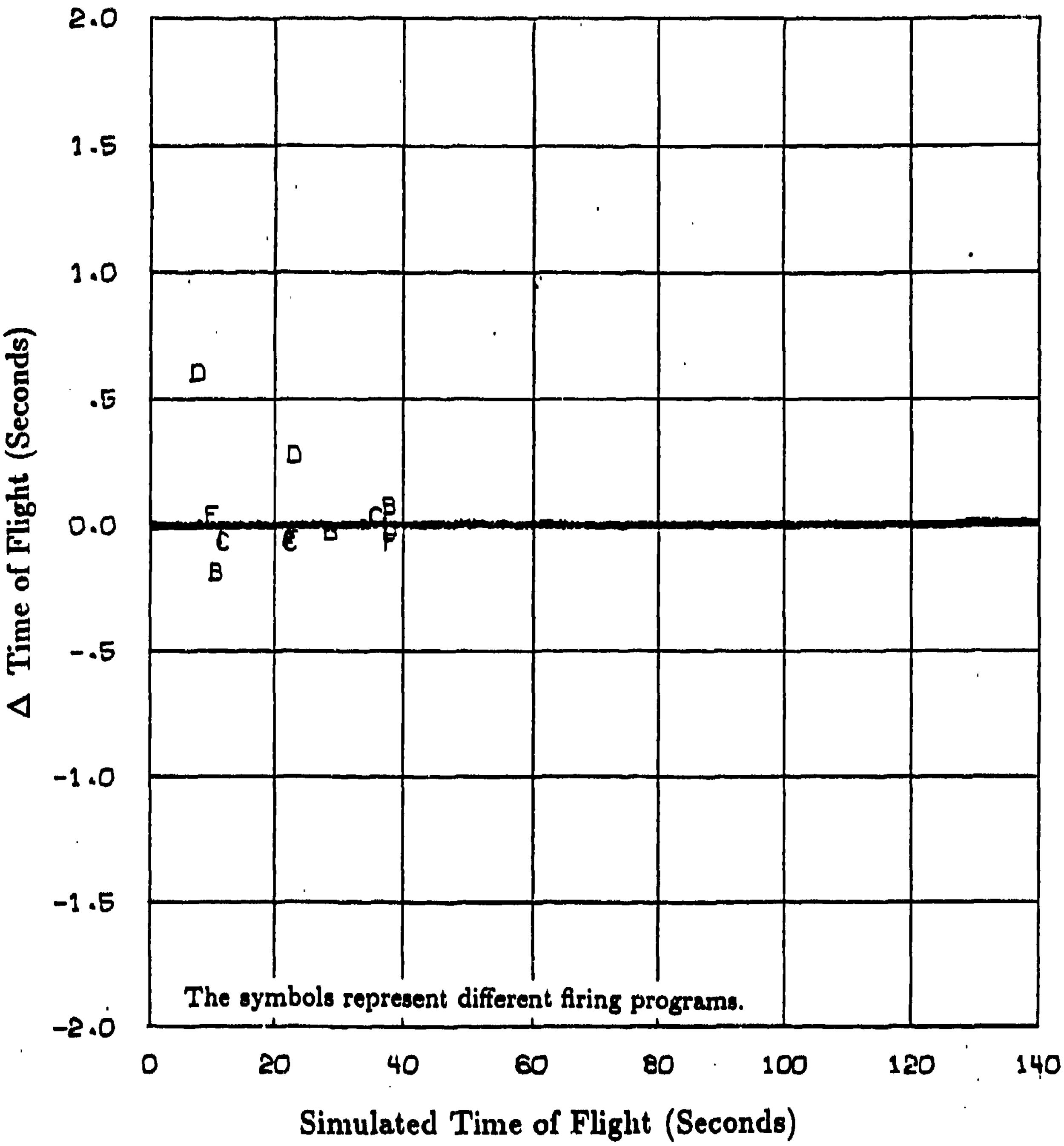

Figure 3. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M3A1, charge 1G.

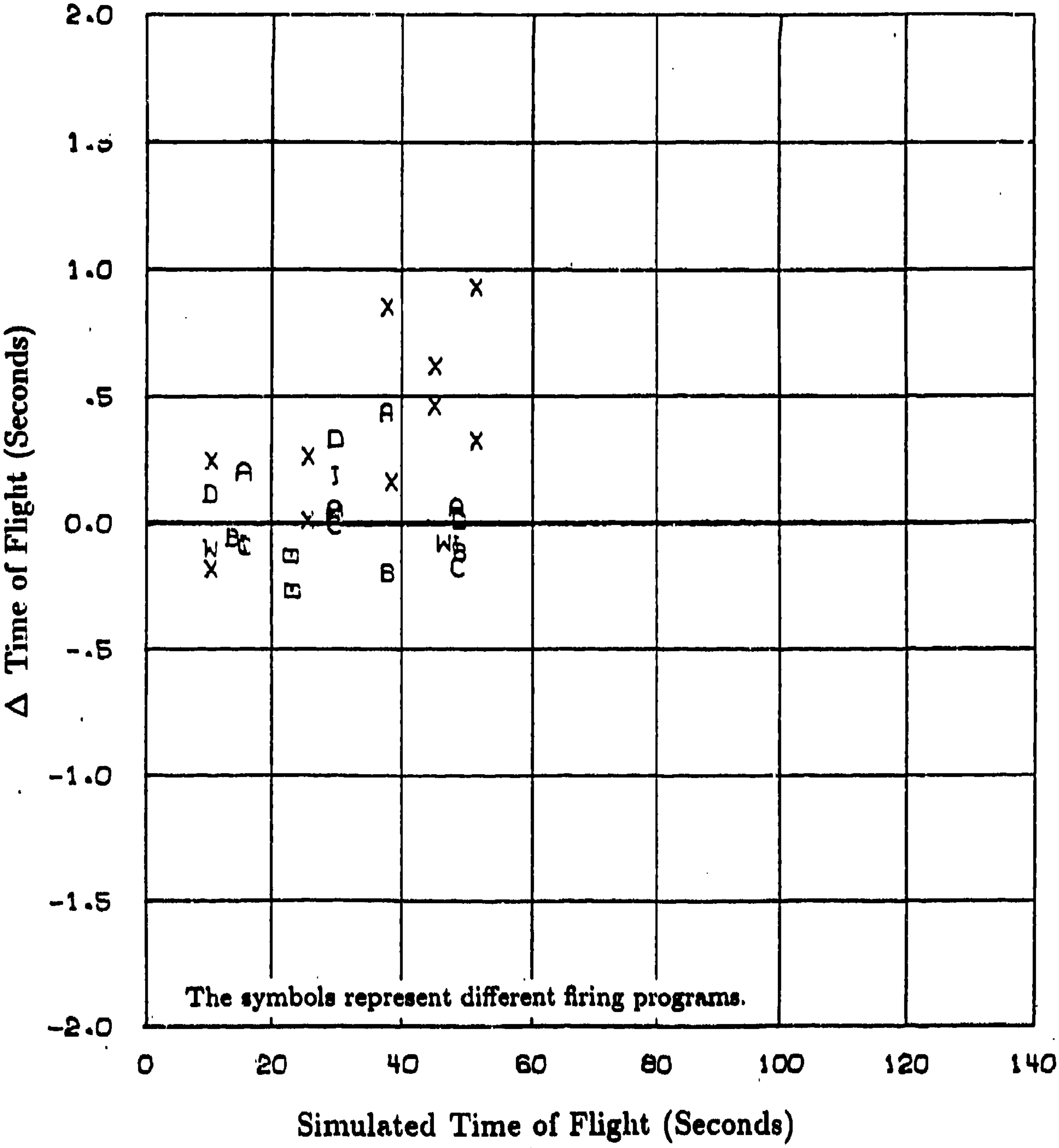

Figure 4. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M3A1, charge 3G.

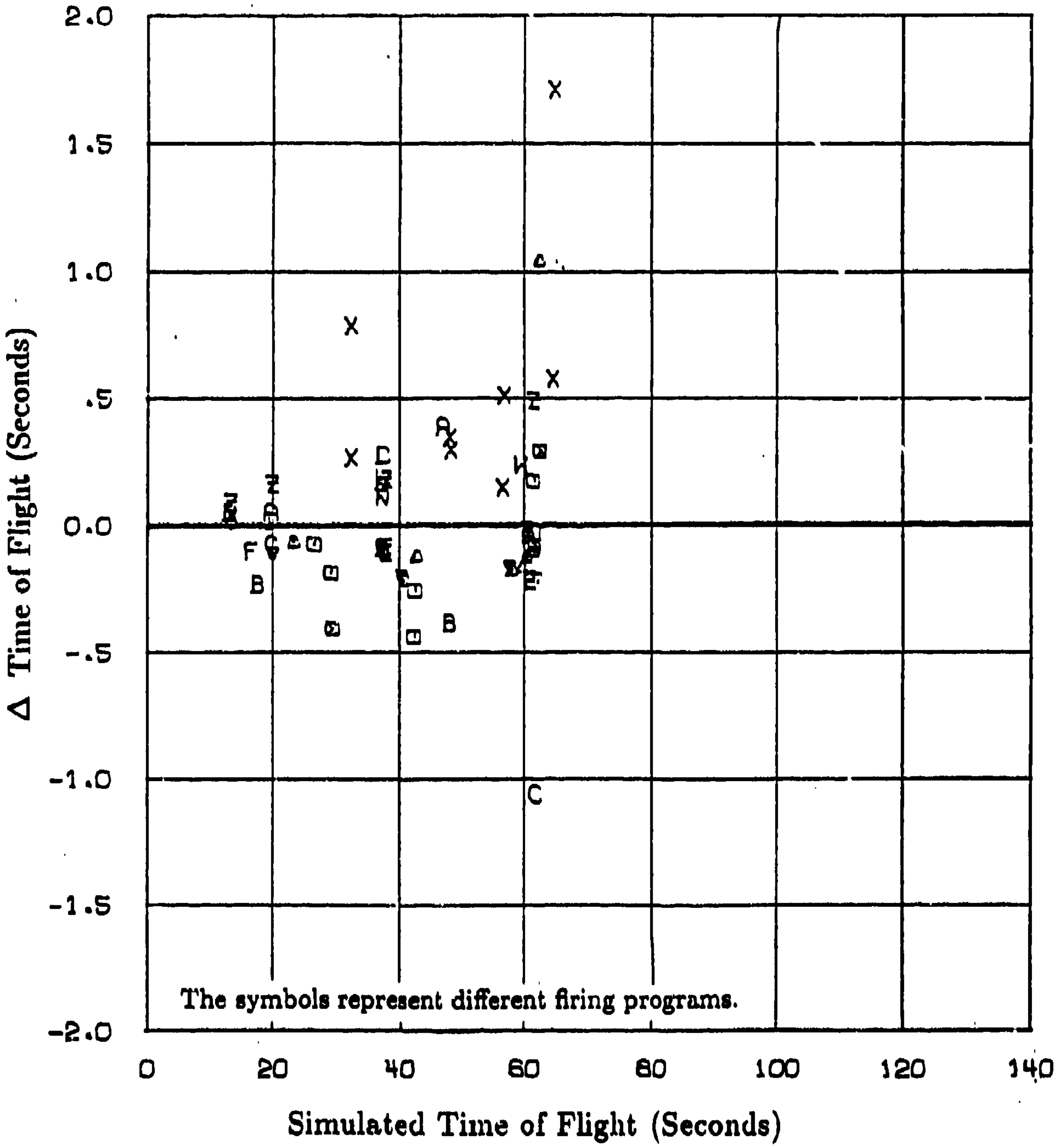

Figure 5. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M3A1, charge 5G.

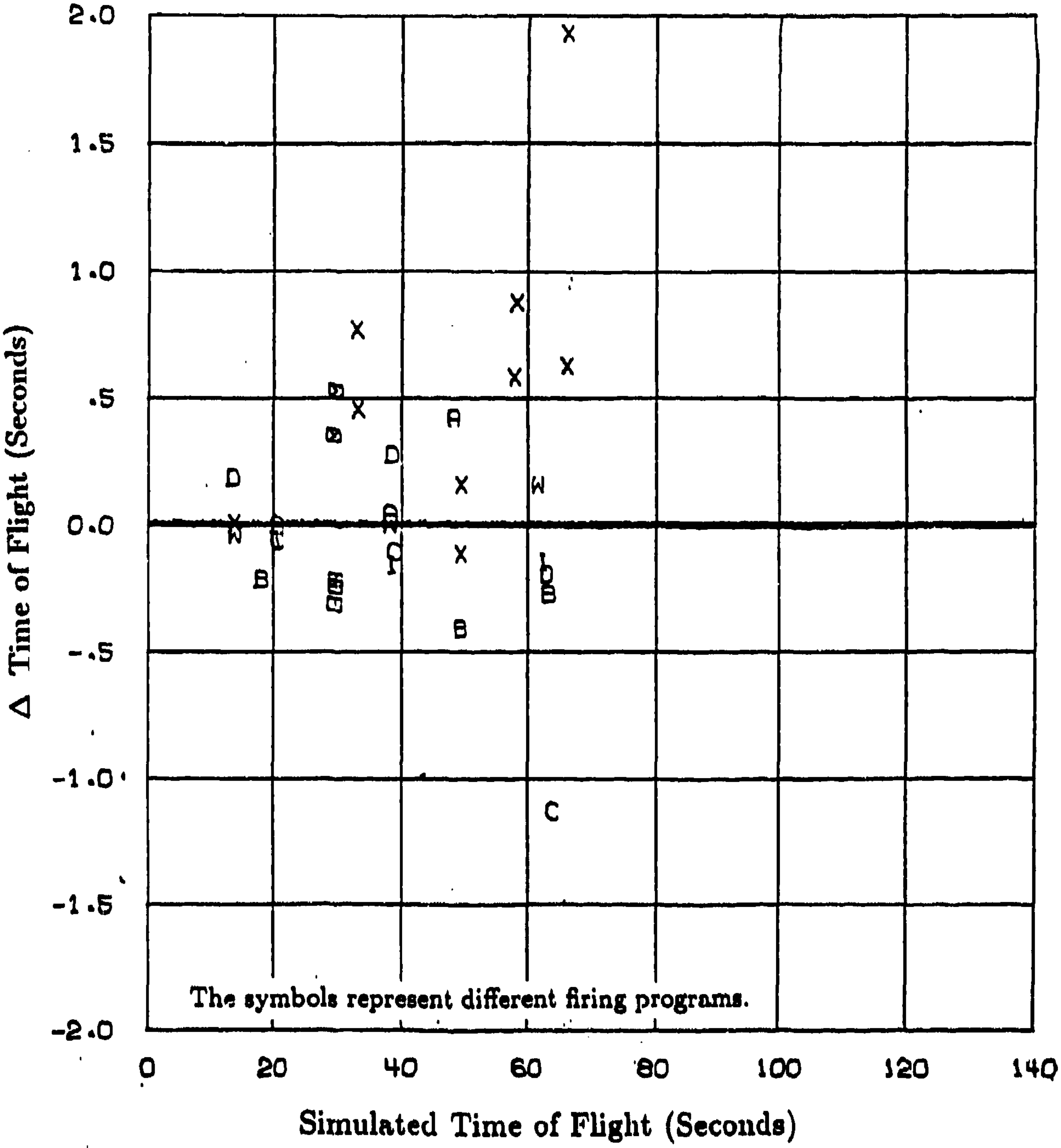

Figure 6. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M4A2, charge 5W.

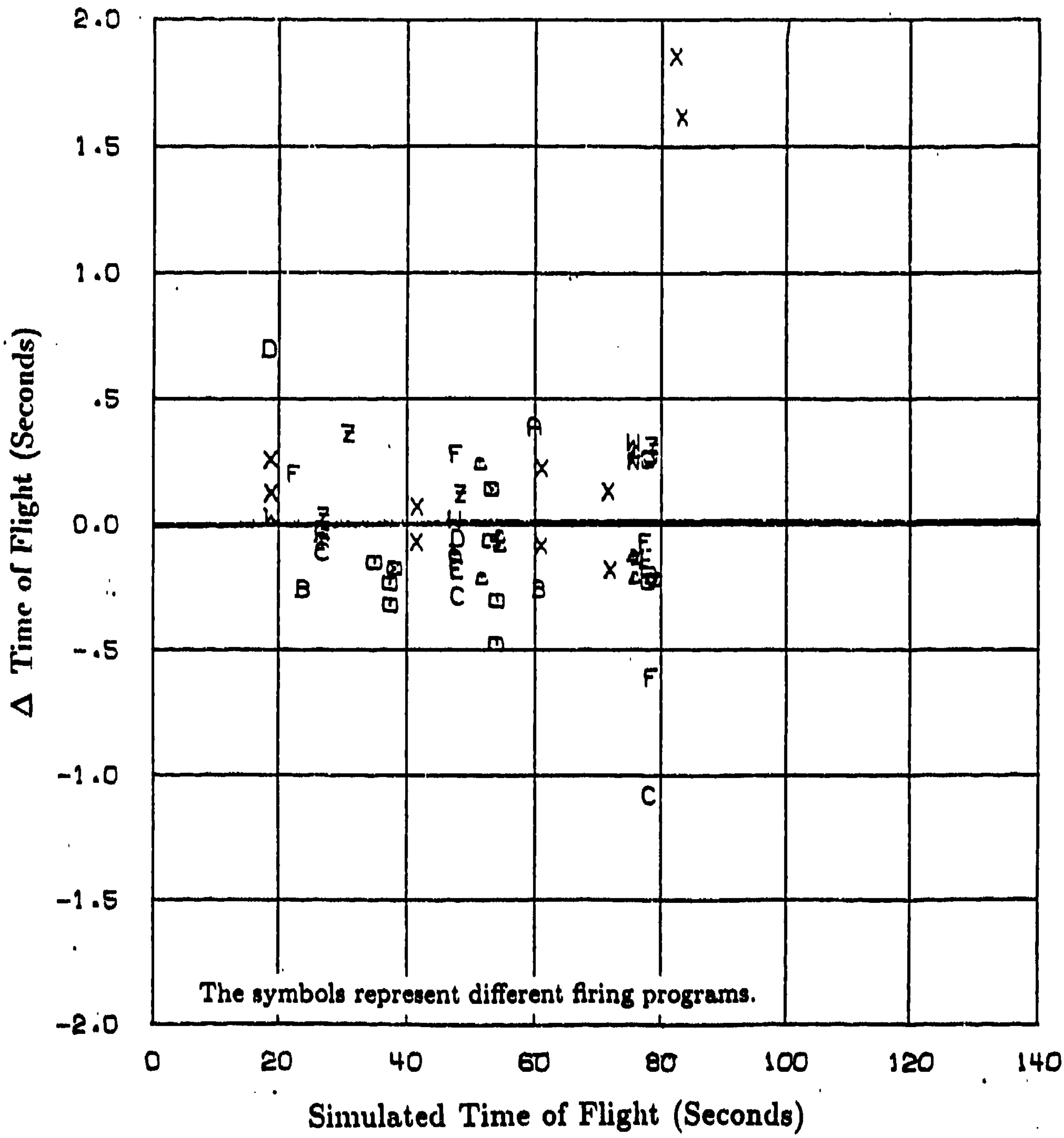

Figure 7. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M4A2, charge 7W.

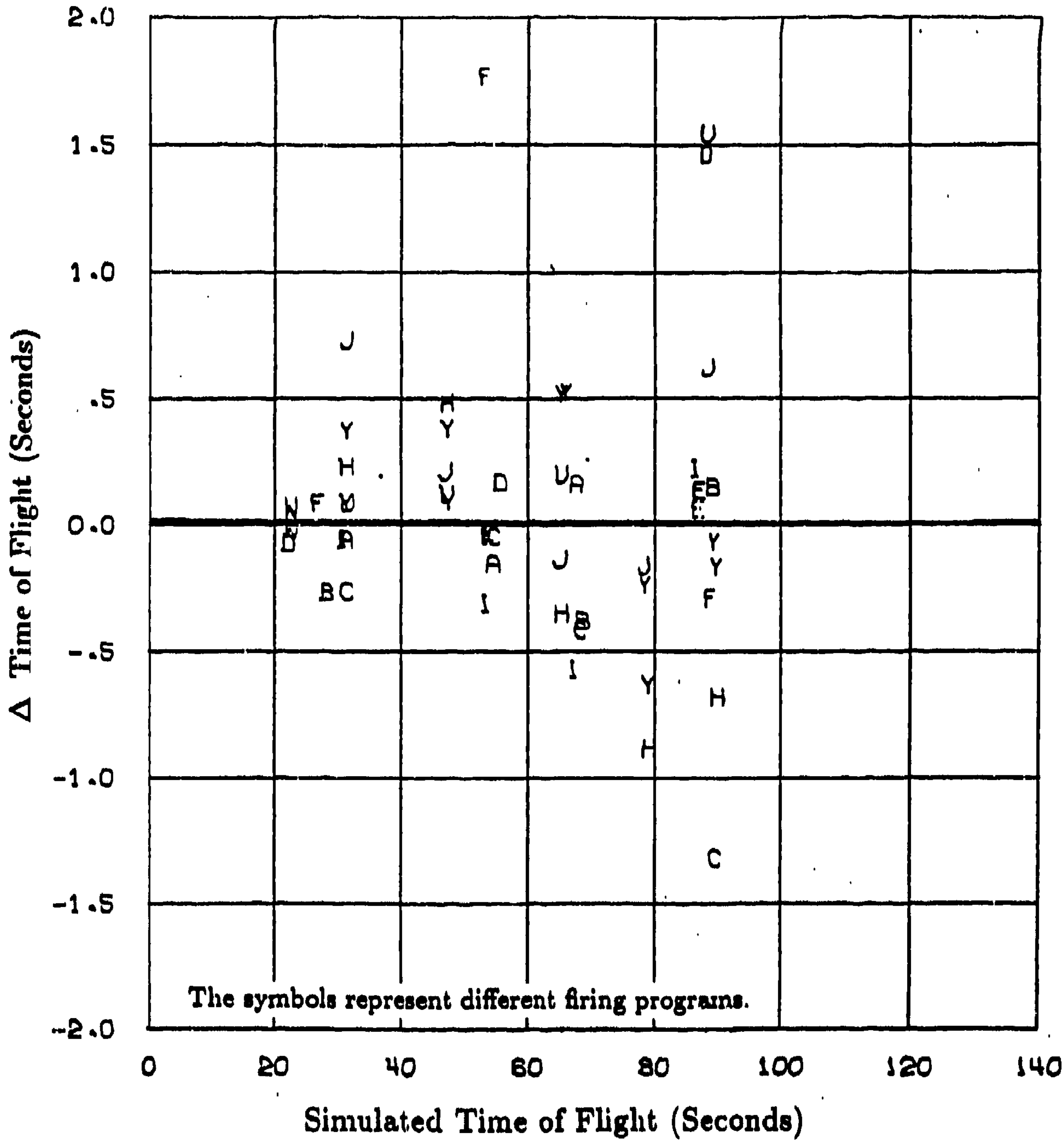

Figure 8. Difference between observed and simulated time of flight (Δ time of flight) versus simulated time of flight for projectile, 155mm, HE, M107 fired with propelling charge M119A1,charge 8.

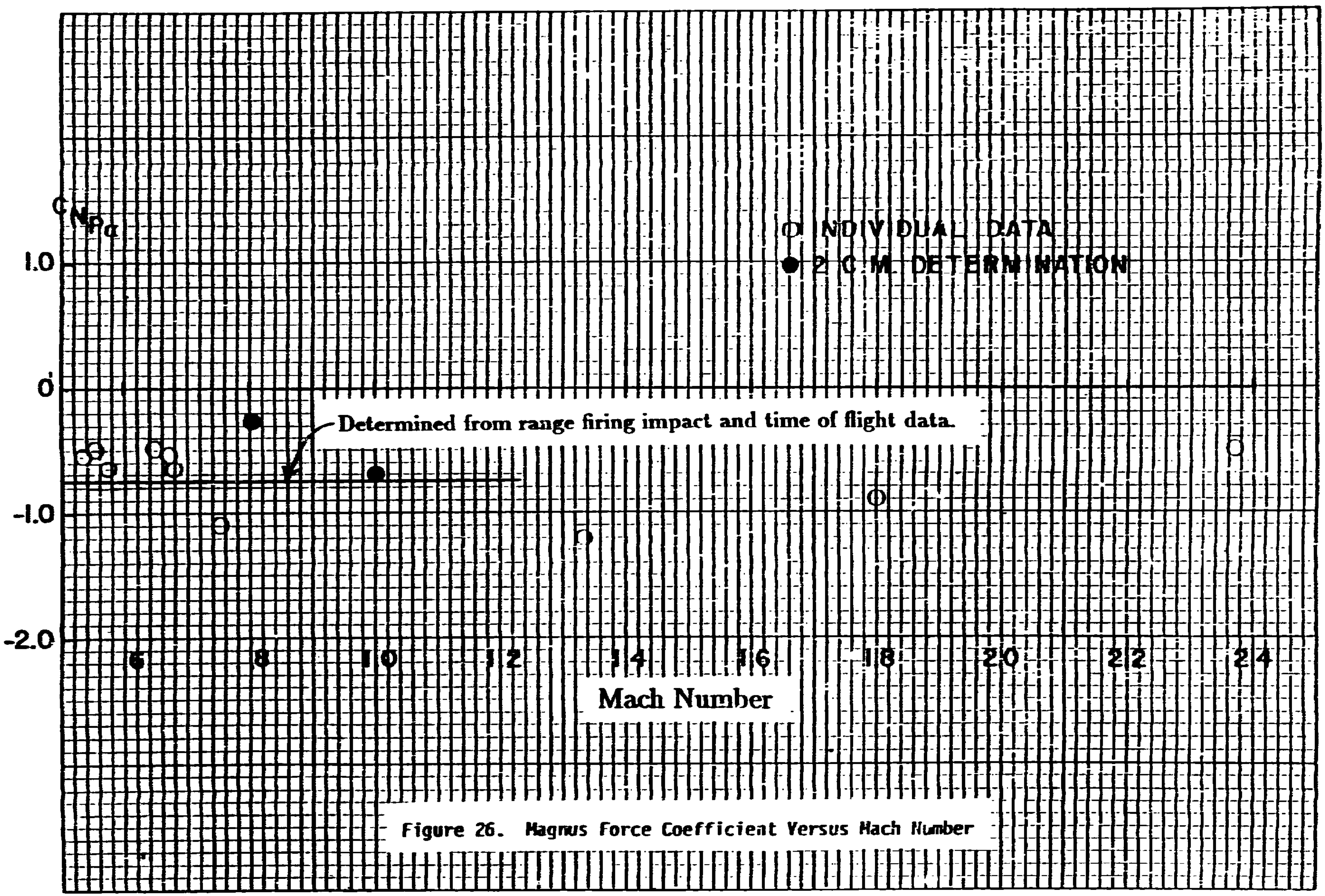

Figure 9. Magnus force coefficient for the 155mm, HE, M107, projectile (Figure 26 of Reference 3) with the effective Magnus force coefficient added.

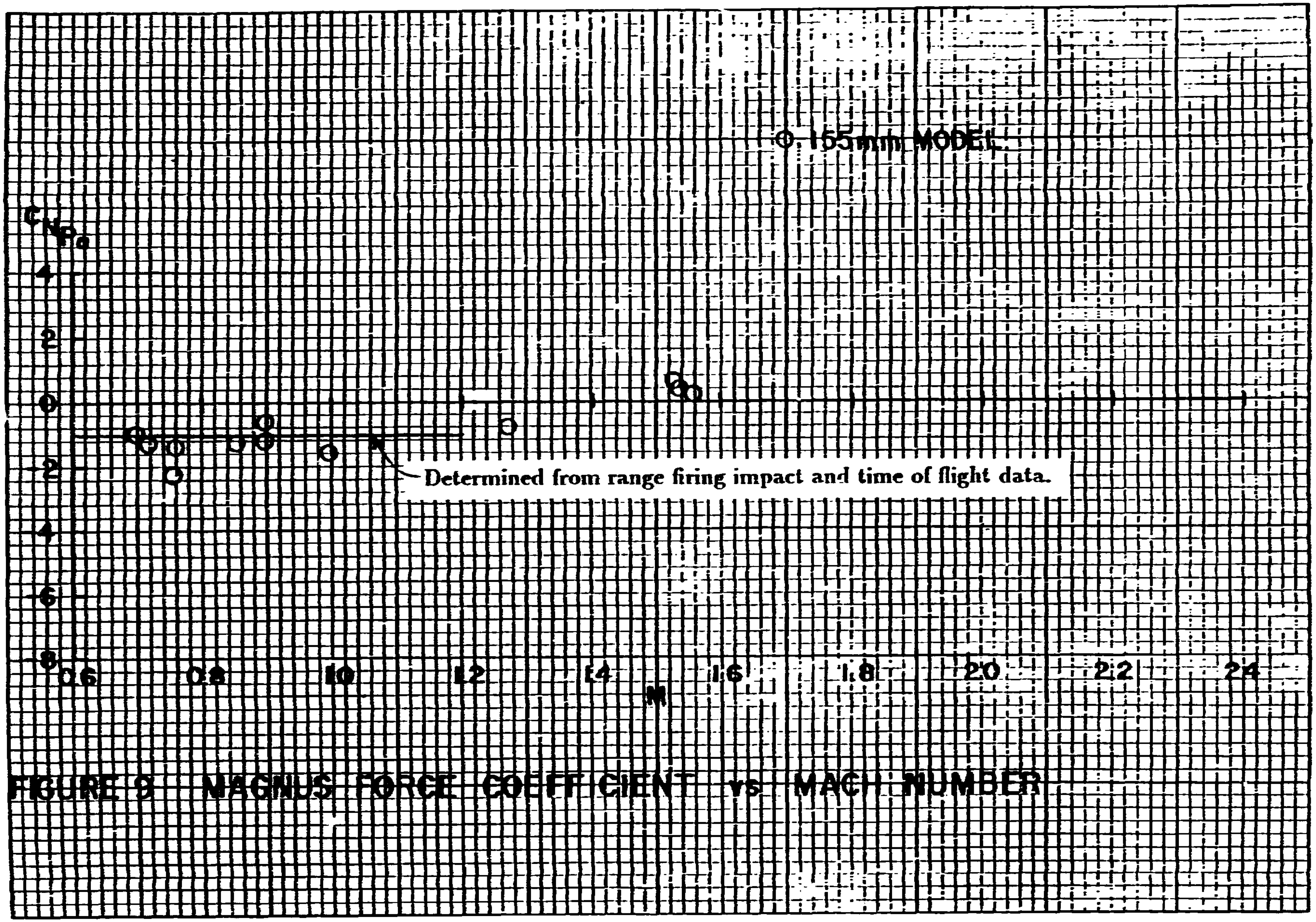

Figure 10. Magnus force coefficient for the 8 Inch, HE, RA, M650, projectile (Figure 9 of Reference 4) with the effective Magnus force coefficient added.

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